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Glossary for new particles and new quantum numbers

BY R. H. DALITZ, F.R.S.

We give some definitions here for the convenience of non-specialist readers. Many words are used with a technical meaning quite different from their everyday meaning. A number of initials are also defined in the Introduction.

Asymptotic freedom. The property which some gauge theories of strong interactions have, that the strong interactions become steadily weaker at high energy and/or momentum transfer, or, equivalently, at short distances.

Charm. A fourth quark attribute C, the other quark attributes being baryon number B, charge Q and strangeness s (or hyperchange $Y = B+s$). The quarks of SU(3) symmetry have charm $C = 0$; a charmed quark has $C = +1$, and the charmed antiquark has $C = -1$. The hadronic interactions for quarks and antiquarks are believed to obey (approximately) an SU(4) symmetry.

Charmonium. Name given to the bound quark-antiquarke system $c\bar{c}$, by analogy with the name positronium for the particle-antiparticle system e^-e^+ well known in electrodynamics.

Colour. A three-dimensional attribute of the quark, acting in a parallel 'colour space' for an internal symmetry SU(3)′. Each quark may exist in three possible states, (fancifully) labelled red, white and blue by M. Gell-Mann. For given (Q, s, C) these three quark states have identical properties with respect to the weak and electromagnetic interactions, and their hadronic forces are SU(3)′ symmetrical. The wavefunction for a hadronic system is then the sum of terms each consisting of three factors, a wavefunction in colour space, a wavefunction in SU(4) space and a wavefunction describing the spin and orbital motions. This complete wavefunction must be antisymmetric with respect to permutations of the labels attached to the quarks, as the Pauli principle requires for spin-$\frac{1}{2}$ particles.

Gauge theories. These stem from the notion that each conserved attribute requires the existence of a local gauge field with respect to which this attribute may be measured. For example, the electromagnetic four-vector potential A_μ plays this rôle for charge Q, and charge conservation is then closely connected with the symmetry properties of the interaction of A_μ with the charge-current four-vector. In general, each conservation principle corresponds to the existence of an internal symmetry group which then implies the existence of a corresponding vector gauge field, as first discussed by Yang and Mills in 1954. The 'gauge particles' are the quanta of these gauge fields and it was believed for a long time that they must have zero mass, as does the photon. Since the only zero mass particles known were the photon (and the graviton, for Einstein's theory is a gauge theory for energy and momentum), this belief was a stumbling block for the general acceptance of the Yang–Mills idea. Quite recently we have learned of a

mechanism known as 'spontaneous symmetry breaking', as a result of which gauge particles can have non-zero mass, in such a way that the finiteness of the theory is retained.

Gluon. The neutral, SU(4)-singlet particles which are the quanta of the colour gauge field. They are vector particles which necessarily form an octet representation for the SU(3)′ internal colour symmetry.

Hadron. Generic name for any particle having interactions of nuclear strength at low energies.

Heavy lepton. Generic name for any leptons which may exist having masses greater than that of the muon. There is one candidate at present, the U-lepton with mass about 1.85 GeV (cf. the paper by B. Richter).

Lepton. Generic name for the particles electron, muon, the neutrinos ν_e and ν_μ, and any other particles which have the same characteristics, namely, that they participate in the weak and electromagnetic interactions but not in the strong interactions.

Quantum chromodynamics, q.c.d. The theory of strong interactions resulting from the hypothesis that they are carried by the gauge field of the attribute 'colour', i.e. by gluons (see above). The name may be compared with q.e.d. = quantum electrodynamics, which is the (Abelian) theory of electromagnetic interactions carried by the electromagnetic gauge field. Q.c.d. is a non-Abelian gauge theory, which means that the gauge field itself has colour and so contributes to the net colour current, so that the equations of motion in q.c.d. are explicitly nonlinear. Only non-Abelian gauge theories can have the property of asymptotic freedom (although not necessarily).

Quark. Hypothetical spin-$\frac{1}{2}$ particles with baryon number $B = \frac{1}{3}$ and which are (with their antiparticles, the antiquarks, which have $B = -\frac{1}{3}$) supposed to be the fundamental constituents of all hadrons.

Quark confinement. Although the evidence is that quarks and antiquarks are responsible for the internal structure of hadrons, no quarks or antiquarks have yet been discovered in the free state, despite vigorous search. The hypothesis of quark confinement is that quark-quark and quark-antiquark forces have the property that it would require infinite energy to remove a quark from a baryon or a meson. Field theories with this property are certainly conceivable, since it does hold for some two dimensional models (in one space and one time dimension) which have been constructed and solved explicitly, but quark confinement has not yet been demonstrated for any field theory in four dimensions.

Unified gauge theory. Generic term for a gauge theory which relates attributes previously considered independent. Frequently used at present for a symmetrical theory which unites electromagnetic and weak interactions by invoking the photon, Z^0 meson and $W^\pm$ mesons as the gauge fields associated with this underlying symmetry. The weak interactions are carried by the W-fields, and appear weak at low energies, having Fermi coupling amplitude $G_F \sim 10^{-5}/M_p^2$, small relative to electromagnetic interactions, which have amplitude $k^{-2}/137$ for (four-

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momentum transfer)$^2 = k^2$. However, for large k^2, these amplitudes will all be comparable in magnitude, according to such a unified theory.

Unified gauge theories of broader scope, which combine the hadronic, electromagnetic and weak interactions into one grand symmetrical interaction, have also been proposed by a number of workers. The paper in this volume by A. Salam provides one example, albeit unconventional and unusually ambitious, of such a unification achieved on the basis of the gauge theory approach.

Weak interactions. The interactions which give rise to the slow decay processes (lifetimes typically 10^{-8} to 10^{-15} s) observed for elementary particles, and which violate many symmetry properties otherwise valid, for example parity-conservation, charge-conjugation invariance, charm and strangeness conservation, and isospin invariance. At low energy (the situation for known particle decays), their weakness is indicated by the Fermi amplitude $G_F \sim 10^{-5}/M_p^2$, but the cross sections observed for neutrino–nucleon interactions rise linearly with E_ν(lab.) and indicate that their effective strength rises continually with increasing energy, until these so-called weak processes may have cross sections comparable with those for photoexcitation processes (cf. Unified Gauge Theory above).

W-meson. The quantum of the carrier field for the weak interaction. The unified gauge theories of Weinberg and of Salam-Ward require the $W^\pm$ states to have mass $37/(\sin\theta_W)$ GeV, where the Weinberg angle θ_W is believed to be given by $\sin^2\theta_W \approx \frac{1}{3}$, so that $M(W^\pm) \approx 76$ GeV, and to couple to the hadronic weak charged current with amplitude $g = e/(\sin\theta_W)$. Their neutral counterpart, which couples with the leptonic and hadronic neutral week currents, is named Z^0 and has mass $M_W/\cos\theta_W \approx 93$ GeV.

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